Drainage Galleries – Investigation, Assessment, Remediation

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Summary

In the engineering assessment and mining-technical remediation of abandoned mine legacies, water-bearing adits in particular represent a technical focal point. The Working Group “Abandoned Mines” of DGGT e. V. in cooperation with DMV e. V. has therefore taken the analysis and risk assessment of the numerous water-bearing adits as an occasion to prepare a recommendation as a basis for safety-relevant objectives and definitions of important terms, including the application of legal provisions, administrative instructions and standards to be observed. The influence of geodynamic processes on the zones of influence and their risk classes, as well as the distribution of their hydraulic properties within the rock

mass, including their perpetual burdens, are also a focus of this practice-oriented partial recommendation.

Preliminary remarks

This partial recommendation is part of a coordinated series of practice-oriented recommendations on dealing with abandoned mine legacies, which Working Group 4.6 “Abandoned Mines” of the Engineering Geology Section of DGGT e. V., in cooperation with DMV e. V., prepares at irregular intervals. The recommendation aims above all at a uniform, efficient assessment of and approach to the investigation, assessment, risk classification, remediation and subsequent use of abandoned mines. The four partial recommendations already available form an important frame of reference for understanding this document.

1 Objective

Water-bearing adits form an underground drainage and discharge system whose preservation and continued existence is an essential prerequisite for stable hydraulic and geotechnical conditions in many mining regions. The adits are also of great importance for the convective transport of mine gas in the overburden. As a perpetual burden of abandoned mines, the permanent, controllable and undisturbed discharge of water determines the fundamental safety-relevant properties for safe use of the ground surface. Of all the damage-relevant legacies of historical mining and of mining yet to be closed, water-bearing adits therefore represent a significant focus in geotechnical, hydrogeological and mine-surveying investigation and assessment as well as in mining-technical remediation.

Water inrushes from adits, caused by uncontrolled accumulation of standing water in the mine workings to be drained or by water falling from the ground surface into mine workings via shafts and stopes during extreme precipitation, floods or thaws, can endanger public safety and lead to considerable damage events. Changes in the physico-chemical properties of the adit water carry potential for environmental damage. Increasing climatic changes in the form of extreme weather conditions place growing demands on the remediation planning of drainage galleries.

Making use of the morphology and the natural gradient, a large number of adits were driven at considerable cost in almost all mining districts of Central Europe to discharge mine and process water and to drain the rock mass. Drainage galleries had and still have a significant importance for abandoned mines. In many cases, they are to be classified as technical structures of the century. They place high demands on investigation and remediation.

This recommendation covers the necessary investigation and remediation measures for drainage galleries from a geotechnical, hydrogeological and mine-surveying point of view. It sets out the required investigation and assessment criteria and outlines the hydraulic boundary conditions.

2 Important types of adits, terms and definitions

The various types of adits and water-bearing mine workings have different functions and tasks to fulfil:

- comprehensive underground and surface discharge of mine water to the receiving watercourse
- drainage of the rock mass traversed and in particular of the deposit
- ventilation of the mine workings
- exploration of the deposit
- extraction of the deposit in the immediate vicinity of the adit
- access and transport route to the surface and underground

The types of adit also give rise to differentiated damage-relevant abandoned mine effects. In the following description, the focus is placed on drainage galleries. Not only active water-bearing adits are to be considered here, but also those that once had this function or may regain it in the future.

Drainage galleries (also hereditary adit (Erbstollen), deep adit, main adit, district adit, royal adit, common adit, fiscal adit, water-bearing adit) are drift-like mine workings for draining the rock mass by natural gradient. They were driven from valley flanks with a slight upward gradient. As main mine workings, drainage galleries can reach enormous lengths (e.g. the Rothschönberg Adit near Freiberg with approx. 50 km), especially as the branching wing drifts (main and secondary branches) are also counted in the total length. Owing to the great lengths, numerous light holes (Lichtlöcher) were often necessary for hoisting and ventilation during the driving of the adits. In particular, it can be assumed that the older an adit and the thinner the overburden, the more light holes were sunk per unit length. Underground branches are referred to as adit branches. The adit also includes the light holes, which were created in particular for ventilation and transport during the driving of the adit. These are primarily vertical shafts that reach down to adit level and served, and still serve, during and after the operating period for the servicing and maintenance of the drainage gallery. Water-bearing drifts are to be classified as equivalent to adits or adit branches.

According to their function, a distinction is made between water, ventilation, haulage, storage and experimental adits. In general, every adit has a portal with a functionally connected drainage channel (Rösche, adit stream) leading to the receiving watercourse. This may be an open or covered ditch or a drift-like channel driven by mining methods. The term Rösche is also used for the water discharge or supply channel for mine and process water used in mining (e.g. for operating water wheels and pumps). Without a functioning Rösche there is no functioning adit. The dimensions of the Rösche should always be based on the flow cross-section of the portal.

Storage adits, such as rock, ice and storage cellars and so-called Höhler, are mostly cavities of limited volume driven by mining methods, often with strongly varying water flow. An Anzucht is a drift driven by mining methods or a stone culvert constructed in open trench for draining deep cellars, above all in the mining towns, usually with low and strongly varying water flow.

The portal is the surface opening of an adit, a surface drift or a Rösche (Rösche portal). It is the interface between the surface and underground and vice versa. The portal includes the wing walls

on both sides, the closure structure and the immediate transition zone (approx. 2 to 10 m) from the existing adit support.

Light holes were sunk as vertical shafts at certain intervals as the driving of an adit progressed, above all to improve ventilation, but also the transport routes during driving and access to new stopes. In most cases, they were numbered consecutively from the portal into the mountain. Owing to the morphology, the depth of the light holes always increased towards the mountain. Where individual light holes were subsequently used as production shafts, changes were made to the cross-section of the shaft, the support and the installations.

Depending on the deposit, the stopes were traversed directly by the adit. Open, partially backfilled, completely backfilled or collapsed stopes generally bound the course of the adit.

Subrosion: this refers to the underground dissolution, transformation, relocation and transport processes in soil and rock, in particular as a result of seepage water, groundwater and mine water movements, including the formation of cavities and their effects on the ground surface.

Karstification (leaching): the totality of all ongoing and completed solution phenomena and forms of soluble rocks and their effects on the ground surface. Karstification is a subset of subrosion.

Groundwater (definition according to DIN 4049): “Subsurface water that continuously fills the voids of the lithosphere and whose ability to move is determined exclusively by gravity”. According to DIN 4049-3 (1994), further subdivisions are made into “unconfined groundwater”, “(artesian) confined groundwater”, “deep groundwater”, “karst groundwater” and “fissure groundwater”.

Mine water (definition of the Mine Water Working Group of the Hydrogeology Section of DGGV): “All water that is or was in contact with underground and open-pit mines. This is predominantly natural water in the form of seepage and groundwater. So-called surface water can, for example, enter the mine workings directly through precipitation and receiving watercourses where there is no overburden. Water from the overburden can enter the mine workings through pores, discontinuities and karst cavities as well as through anthropogenic loosening, e.g. shafts. Deep groundwater, in some cases with a high mineral content, can flow into the mine workings from the adjacent and underlying rock mass. The definition contains no statement on the quality of the mine water. This varies greatly depending on the genesis of the mine water.”

3 Legal provisions, administrative instructions and standards to be observed

When dealing with drainage galleries, the applicable legal provisions, such as regulations under water, soil protection, nature conservation and building law, must be observed. With regard to standards, reference is made in particular to the other recommendations of Working Group 4.6 and to EC 7.

For the capture and discharge of mine water, it must be examined in each individual case whether a permit is required. For this purpose, the quantity and quality of the water are to be determined. With the results, a corresponding enquiry or even an application is to be submitted to the respective competent authority. The authority can often provide relevant information for the

remediation planning of a drainage gallery. Likewise, a temporary diversion of adit water as part of the mining-technical remediation measures may require a permit.

4 Brief historical outline of adit driving and Rösche construction with specific mining law

From as early as the 11th century, silver and gold mining in particular, as well as the extraction of various other metals and salts, became increasingly important in Central Europe. The importance of water-bearing adits is also evident from the extensive codifications in the various mining ordinances.

The Iglau and Freiberg mining laws of the 13th and 14th centuries formed the first foundations of mining law in this respect. The drainage of deposits was also regulated by mining law. Owing to the high cost of a drainage gallery, driving by individuals was generally not affordable. Only the participation of the feudal sovereigns in mining and the emerging formation of mining partnerships (Gewerkschaften) of wealthy merchants laid the financial foundation for the systematic and extensive driving of drainage galleries (hereditary adits). On the basis of regalian mining (rights of the sovereign), adit construction in ore mining was reorganised from the 15th century onwards through the participation of wealthy merchants and the sovereigns. The Schreckenberg mining ordinance of 1499/1500 for the Annaberg district became a trend-setting mining ordinance. It was based on the emerging centralised management of mining (directorate principle), which also regulated the handling of hereditary adits (drainage galleries) at district level. For the first time, this mining ordinance laid down the required dimensions of a hereditary adit. On the basis of this Schreckenberg mining ordinance, the Annaberg mining ordinance was issued in 1509 by Duke George of Saxony as the oldest fundamental mining ordinance in Germany. Until the second half of the 19th century, it was the legal basis of all mining ordinances in Central Europe.

In order to promote mining after the Thirty Years' War, the construction of hereditary adits was encouraged in the German mining districts. The separate Saxon Adit Ordinance of 1749 served this purpose. It regulated the mining framework conditions for hereditary adits, their financing and maintenance as well as the rights and obligations of the adit owner (Stöllner). This adit ordinance includes, among others, the following selected key points:

- acceptance, claim application (Mutung), entitlement and hereditary share (Erbkux) by the adit owner
- hereditary depth (Erbteufe): 10 fathoms (Lachter) vertically and one span below the grass sole or below the hereditary adit above in Saxony, 7 fathoms and one span in Prussia, 9 fathoms vertically and one span in other countries

  Note: The dimensions differ in detail between the individual countries and in some cases also between the districts, which must be taken into account in the geotechnical and mine-surveying assessment. The range of variation for one Lachter is between 1.92 and 2.09 m (historical unit of length: 1 Lachter ≈ 2 m on average)
- adit right of extraction (Stollenhieb): share of extractable ores won by the adit owner during driving, with maximum dimensions of 2.5 m height and 1 m width

- Gesprenge: step in the adit floor resulting from raising the base of the deposit
- servicing and maintenance of the adit
- gradient of the floor: "… not to permit more than a quarter fathom of Rösche or rise for every hundred fathoms of length."
- adit cross-section: 1 m wide, 2 m high, in some cases also different
- driving of the adit and its main and secondary branches
- location and function of the shafts and light holes along the adit route
- fees and taxes paid by users and operators to the adit owner (e.g. adit ninth (Stollenneunter))
- securing support of the adit (timber, masonry)
- construction and maintenance of the water channel (Wasserseige)
- "disinheritance" of a hereditary adit when a new, deeper adit is driven

With the respective technical development of mining-related driving, the adit cross-sections to be driven were also adapted. For example, according to the Saxon Mining Act of 22 May 1854, the adit floor was only permitted to have a gradient of between 30 and 100 mm over a length of 200 m. The water channel was to be 1 m wide and deep. Above it, a clear height of > 2.5 m was specified.

With minor changes and additions, the adit ordinance had also been incorporated into mining legislation for the granting of hereditary rights until about the beginning of the second half of the 19th century. During this period, the general mining acts of the Kingdoms of Saxony and Prussia came into force, which in turn served as models for other German states. The triggers for the partly fundamentally changed provisions of mining law were the end of the directorate principle and also the technical progress of the developing mining industry of the German Empire. Mine water was lifted to the existing adit level by steam and electric pumps. Water discharge adits thus no longer received hereditary rights. Their special status under mining law thus expired. In some districts, the existing drainage galleries continued to be used and maintained for drainage. With the closure of numerous mines, especially at the end of the 19th century, inspections and maintenance were increasingly neglected, as a result of which the functionality of the drainage galleries deteriorated considerably for the most part and damage-relevant failures accumulated, in particular during heavy and extreme precipitation.

According to the provisions of mining law, a hereditary adit had to meet the following minimum geometric dimensions (General Mining Act for the Kingdom of Saxony of 16 June 1868, § 121 Hereditary adits):

- vertical height: 1.25 Ltr. (2.5 m); lower width: 0.5 Ltr. (1.0 m) up to a height of 0.5 Ltr. (1.0 m)
- hereditary adits are to be driven without steps (Gesprenge).
- rise of the adit floor: not more than 0.1 Ltr. (0.2 m) and not less than 0.03 Ltr. (0.06 m) per 100 Ltr. (200 m)
- the "hereditary adit owner" must maintain the water channel of the adit so that it carries water and must ensure full functionality at all times through cleaning and maintenance.

> Note: In the geotechnical and mine-surveying assessment of the objects, it must be taken into account that, according to experience, the minimum geometric specifications for drainage galleries may have changed over the past centuries, e.g. owing to the deposit and technology.

Driving drainage galleries may also play an important role in the remediation of abandoned mines in the future.

5 Hydraulic and hydrogeological principles

5.1 Hydraulic principles

The water flow in the adits is subject to considerable seasonal and precipitation-related fluctuations. The mining influence on the overburden leads to loosening around the mine workings, which increases the drainage function of the adit. In principle, it must be noted that the real underground hydrogeological and hydraulic conditions are very difficult to model. The mine plans and hydrological information provide essential basic data. The geotechnical and mine-surveying assessment focuses on the following key points:

- The adit system is in good functional condition and discharges the mine water unhindered and evenly to the receiving watercourse. Fluctuations due to precipitation and inflow are handled without difficulty.
- The discharge of adit water is obstructed in its continuous flow by one or more partial collapses. This frequently leads to backwater, including sediment deposits and ochre precipitation. As a result of these partial collapses, the adit cross-section has “nozzle-like” constrictions, which increase the flow velocity of the water and allow further collapse potential to develop as a result of the backwater.
- Triggered by extreme precipitation and by surface water falling directly into near-surface stopes and/or shafts, the adit has collapsed completely. Considerable backwater in the entire mine workings leads to uncontrolled water discharges from higher, mostly older adits or other mine openings to the surface. Backfilled shafts, crown holes, stope trenches and other connections to the surface can lead to safety-relevant deformations at the ground surface as a result of the vertical and horizontal mobilisation of loose material.
- The basic hydraulic properties of a drainage gallery are retained even without water flow. They are reactivated during extreme water events, rising groundwater or mine water or backwater associated with the formation of standing water. The principle therefore applies: “Once a water-bearing adit – always a water-bearing adit!”
- The closer a partial or complete collapse or a change in cross-section, in particular a narrowing of the cross-section, in a drainage gallery is to the portal, the greater the damaging effects to be expected in the event of extreme water events, rising groundwater and mine water or backwater.
- In addition to the main course of the adit, adit branches, water-bearing drifts and shafts are of equal functional rank from a hydraulic point of view.

5.2 Surface and underground water inflows and their effects

- Above all during extreme precipitation and deformations in the adit area, there are various possibilities for surface water ingress: particularly during heavy rainfall, various surface water inflows can lead to widespread flooding. In the case of direct inflows into old shaft depressions, deformation zones, fissures, broken-through stopes at seam and vein outcrops as well as adits and drifts, these can further restrict the water pathways – reinforced by the relocation of collapsed and fallen material in the mine workings and in the adit section.
- Water flow in the overburden above the adit section generally triggers subrosion processes. Fine-grained material can enter the adit through discontinuities, pores and open masonry joints and thus lead to sanding up, silting and accumulations of ochre.
- When the water levels of the receiving watercourses are high, surface water can also flow back through the adit into the mine workings and lead to destabilisation of the rock mass and of the adit support.
- In the event of adit collapses within the mine workings, groundwater and mine water can also drain through other mine openings to the surface or collapse zones as a result of backwater and/or the formation of standing water.

In general, where mining has taken place in rock and soil, the hydrogeological and hydraulic conditions are disturbed, since natural water pathways such as joints, rock boundaries, perched groundwater horizons or faults have been intersected or destroyed. Artificial groundwater or mine water catchment areas may form. These can extend far beyond the boundaries of the mining district under consideration. Neighbouring drainage galleries may form spatially different groundwater or mine water catchment areas and influence each other as open systems.

5.3 Determination of water quantity and water quality

On the one hand, a drainage gallery fundamentally has a draining effect on the entire rock mass beneath which it passes. On the other hand, it has to discharge groundwater and mine water from the mine workings unhindered and in a controllable manner, making use of the natural gradient. In addition to the focus of a geotechnical and mine-surveying investigation and assessment, drainage galleries are also of interest with regard to what they transport, namely water. Statutory requirements for the characterisation of surface waters, such as the European Water Framework Directive, require a (re)assessment of drainage galleries with regard to their environmentally relevant perpetual burden, the often highly mineralised mine water. Mining can thus lead to localised or small-scale inputs of high pollutant loads that may pose a hazard to groundwater or surface water (prohibition of deterioration).

Drainage galleries can be assessed as the link between the receiving watercourse and the flooded mine on the basis of chemical measurements. In order to obtain an initial statement on the discharge, its natural fluctuations and the water quality of an adit, it is advisable to determine these parameters at the adit portal. The relevant regulations and recommendations are to be observed. For a precise investigation of the behaviour of the water quantity and quality, it is necessary to carry out an adapted monitoring programme (see Section 7).

If possible, water inflows into the adit should be recorded and their quantity and chemical composition determined (inflowing groundwater and seepage water, rising mine water from the flooded area). The quantities of water transported through the adit and their velocities can be determined, among other things, by using tracers.

The hydrochemical measurement is carried out in two parts. On site, parameters such as temperature, electrical conductivity, redox potential, oxygen content and pH value are determined. At the same time, it is important to determine the prevailing air pressure. In the laboratory, task-specific analysis of environmentally relevant elements is carried out, on the basis of which processes such as ochre precipitation, sedimentation or leaching can be described. Depending on the task, the parameters to be determined and the respective investigation effort may be based on the Drinking Water Ordinance, the water acts of the federal states, the Mineral and Table Water Ordinance and, in the case of medicinal water, the Medicinal Products Act.

Damage events such as collapses or heavy rainfall events can also be derived from the loads determined. Interactions between the hydraulic and the hydrochemical properties can also be inferred.

With regard to a review under water law of the discharge of mine water into a receiving watercourse, an analysis of the dissolved constituents and suspended solids in the mine water is necessary for a meaningful evaluation, in accordance with the state-specific requirements and in consultation with the competent authorities (mining authority and water authority). In addition, the hydrochemical analysis with regard to aggressiveness to concrete and steel (DIN 4030-1 and DIN 50929-3) must be taken into account in view of future remediation measures. When assessing the analysis results, the geogenic background must not be neglected. With a view to reducing the input of environmentally relevant elements into the receiving watercourse, a local adjustment of the limit values may be necessary. If necessary, water treatment measures (water remediation) may also be required.

5.4 Effects and consequences of extreme weather events

Weather-related, damage-relevant events for drainage galleries include, for example, extreme rainfall events, extreme cold or heat leading to above-average drought. All these phenomena affect the functionality of the adit section and the long-term stability of the adit perimeter, including the adit branches and water-bearing drifts.

Heavy rainfall events can cause an exceptionally large amount of water to penetrate the overburden/the rock overlying the adit, which can lead to severe erosion and subrosion processes. Possible failure of the load-bearing capacity of the overburden/the rock overlying the adit then leads to partial and complete collapses, preferably where the overburden thickness decreases towards the portal or in unstable or faulted rock zones. Adits and surface drifts are considerably destabilised from the portal inwards by the chimney effect during intensive frost. Frost damage to the adit perimeter in unsupported sections not infrequently extends more than 100 m from the portal, depending on the air flow. Above all, frost-sensitive rocks are limited in their durability, and appropriate mining-technical securing measures and ventilation control are required at the portal to minimise the effects of frost.

6 Geotechnical and mine-surveying investigation and assessment

6.1 Data basis for the investigation and description of the adit system

In a geotechnical and mine-surveying description and assessment of water-bearing adits, the situation recorded by surveying in the mine plans and other documents on the mine workings (including the surface situation) represents an essential basis. Supplementary and updating surveys at the surface and, if possible, also underground allow adequate georeferencing and checking of the mine plans and other documents with regard to the adit route. This takes into account the light holes and shafts as well as the damage-relevant manifestations in the entire hydraulic zone of influence.

In the majority of cases, however, it must be assumed that the available older mine plans do not reflect the final contour of the mine workings, or that plans are only partly available or not available in full. Existing files, expert reports and technical literature on the adits and on the geology are also to be included in the geotechnical and mine-surveying assessment. Information on the cross-section and inclination is of particular interest.

Necessary prerequisites for a stability assessment are the updated mine-surveying documents and an engineering geological mapping as well as supplementary documentation (e.g. photos, videos, etc.) of the accessible parts of the adit.

6.2 Rock-mechanical assessment of the overburden above the adit system

In a rock-mechanical assessment of the overburden above the adit system, a fundamental distinction must be made between soil and rock. Water-bearing adits in soil are generally supported. Natural stone and brick, but also mine timber, and in more recent drivings and repair measures steel support, anchors (nails), steel mesh and shotcrete were used.

Water-bearing adits in soil as well as in rock are subject to permanent effects on their long-term stability as a result of geodynamic processes. This applies above all to the constantly acting physical, chemical and biological weathering processes. However, changes in the rock-mechanical and soil-mechanical situation also become clearly apparent depending on the depth. To assess the constantly changing overburden of an adit, the horizontal and vertical changes in properties must be taken into account.

According to experience, a rough vertical zoning of the overburden can be made as follows:

Very shallow zone (0 to 20 m, ± 10 m)

Mining at a depth of 0 to 20 m (± 10 m) below ground level (soil) or below rockhead (rock) is referred to as very shallow. In this depth zone, weathering has an intensive influence on the fabric and the soil constituents (loosening, dissolution, subrosion). In this depth range, a large proportion of the pores in the sedimentary layers and of the joints in the rock are filled with air. The prevailing fabric structures (faults, joints, bedding and their orientation in space) and stress conditions have a great influence on the long-term behaviour and stability of the mine workings. There is usually an

intensively disturbed stress state. The morphology and the existing buildings and use also have an influence. In this depth range, overburden pressure dominates in rock. In soil, lateral and floor pressure additionally lead to deformations. Effects of surface water on rock- and soil-mechanical properties are to be expected in this depth zone.

Near-surface zone (20 to 50 m, ± 10 m)

In near-surface abandoned mines at a depth of 20 to 50 m (± 10 m) below ground level (soil) or below rockhead (rock), overburden pressure and lateral pressure increase progressively. The fabric and the influence of geodynamic processes are largely determined by glacial overprinting. In contrast to very shallow mining, the intensity of weathering decreases sharply at this depth. The pores of the soil or consolidated soil form the water pathways. Permeability is predominantly material-dependent. A layered structure with several superimposed aquifers and aquitards is characteristic. This depth zone is largely influenced by groundwater. The old mine workings are usually water-filled below the deep drainage gallery. Existing timber support is hardly affected by decomposition processes here. The occurrence of crown holes is considered lower for near-surface abandoned mines than for very shallow abandoned mines. However, crown holes can still occur. They are favoured by the presence of thick quicksand horizons and by interventions in the hydrogeological equilibrium.

Deeper zone (> 50 m, ± 10 m)

In this depth zone, chemical weathering has only a very slight influence on the rock and rock mass. Essentially, a three-dimensional stress state prevails. The permeability along joints is further reduced. Lithological changes and faults are prominent water conductors. In the case of vertical vein or seam mining, numerous pathways exist under these mined-out deposit conditions from the ground surface down to the deepest adit level. Material relocation, partial and complete collapses as well as deformations in old support considerably alter the discharge situation of the mine water from the adit section. In principle, it can be assumed that the soil and rock mass is to be classified as loosened to very different degrees by mining. The intensity of loosening can range from a broken rock mass to a largely only slightly deformed rock body. It should be noted here that the deformations and changes in substance proceed over the long term and irreversibly, depending on the rock and rock mass properties. (Note: thick soil covers are to be taken into account.)

For the portal area, the immediate overburden and the vegetation or surface use are of particular interest. Here, deformation phenomena such as masonry damage, cracking, slides, ingrowth of tree roots, waterlogging and vandalism occur to an increased extent, which often leads to functional disruptions of the water discharge. Owing to possible disruptions of the free water discharge and the massive effects of geodynamic processes, the portal area is one of the critical, damage-relevant problem zones of a drainage gallery. Possible narrowing of the adit cross-section and thus of the outflow cross-section, e.g. through the installation of pipes that reduce the cross-section, masonry deformations or dam construction in the portal area, lead to larger, catastrophic damage, above all in the case of extreme or heavy water flow. In light holes that have remained open and unused, the geodynamic processes have been able to act unhindered over a long period. In particular, weathering processes and frost, but also rock pressure, alter the long-

term stability of the shaft tube with its installations and support. These findings apply above all to the very shallow rock zone. Water inflows and waterlogging from the very shallow rock mass reduce the durability and stability of the partly supported shafts.

Furthermore, the driving of the adit itself, depending on the driving technology (e.g. hammer and chisel work, blasting technology), results in different depths of loosening around the excavated cavity. If, as a result, no long-term stability can develop in the zone around the adit excavation, permanently effective mining-technical securing measures are required. These loosening effects are further promoted by rock mass water flowing into the adit (spatial drainage effect). The durability of the adit contour depends decisively on the compactness, strength and weathering resistance of the in-situ rock mass and on the quality of the securing support. Stability problems frequently arise in adit sections with soluble rocks (salt, gypsum, anhydrite, limestone).

Should the rock mass yield, only a force-locking stabilisation of the contour by mining-technical measures can help. The original stress state in the rock mass cannot be restored by mining-technical measures. On the contrary, the existing stresses and rock mass stability are always consumed over time. Since a water-bearing adit is a perpetual burden of abandoned mines, it follows that it requires periodic inspection, maintenance and upgrading.

The geomechanical influences around the adit cavity are also reflected in larger fluctuations in water level during extreme precipitation. Triggered by extreme weather conditions, collapses and relocation of material may increasingly occur along the entire adit route, which can lead to considerable damage-relevant failures.

The permanent effects of geodynamic processes result in a large loss of safety. As a result, obstacles to free water discharge may increasingly arise. Backwater forms, in some cases with serious consequences due to the mobilisation of collapsed and fallen material in stopes and collapsed shafts, as well as in the event of a sudden water inrush in the portal area. Shafts, light holes and near-surface stopes are also flooded. This leads to crown holes, other deformations at the ground surface and often to permanent waterlogging.

In the area of the stopes, the collapses in numerous cases extend into the immediate water discharge and lead to more or less extensive backwater. Prompt elimination of this situation is advisable. In general, under intact conditions, it can be assumed that the sidewalls and the roof discharge mine water at points, over areas or along lines. A further problem arises from old timber, which on the one hand rots and thereby weakens the mine working. On the other hand, timber can enter the adit discharge, causing jamming, which in turn can lead to backwater.

Significant changes in the rock mass water table and water flows in the overburden, including in soil, influence the stability of the in-situ rock mass and of the existing mining-technical remediation measures. In this context, it must be taken into account that in mining-technical measures the drainage function must always be maintained, not only for water but also for mine gases.

Geodynamic processes, and in particular the influence of frost, have a safety-relevant influence on the long-term stability in the first section of the adit.

6.3 Geotechnical and mine-surveying documentation of condition

Water-bearing adits are, in principle, technical structures whose function must be ensured permanently. In this respect, special requirements also apply with regard to maintenance and monitoring.

As a result of the permanent effects of geodynamic processes on the adits and/or their surroundings, there is naturally a loss of safety. This can be intensified, particularly in the event of extreme weather conditions. As a result, obstacles to free water discharge, such as collapses and relocation of material, may arise increasingly or suddenly. Backwater forms with unforeseeable consequences due to the mobilisation of collapsed and fallen material in mine workings. Furthermore, sudden water inrushes may occur in the area of mine openings to the surface. In terms of damage patterns, these processes lead to crown holes, other deformations at the ground surface, flooding or permanent waterlogging.

In this context, water-bearing adits should be classified as structures of Geotechnical Category 3 in accordance with DIN EN 1997-1/Eurocode 7.

The approaches of a geotechnical and mine-surveying assessment apply to the general assessment of drainage galleries (see previous recommendations of Working Group 4.6). This includes, in particular, historical research at the beginning of every inspection or measure. For the condition documentation of water-bearing adits, the following subject areas must essentially be taken into account:

Geotechnics

- geology, tectonics and deposit conditions and their assessment with regard to the strength and deformation behaviour of the surrounding rock mass and of the contour of the support
- types and intensity of weathering, extent of sedimentation in the floor area and other deposits in the adit
- extent and intensity of dissolution of karstifiable rocks
- detailed recording of active damage zones
- inspection and maintenance, monitoring

Hydrogeology

- groundwater conditions in the inflow and outflow areas
- influences of water level fluctuations on the behaviour of the overburden
- catchment area and flow volumes in the portal area, from the adit branches and water-bearing drifts
- chemistry and its changes over time, discharge temperatures

Mine-surveying work

- georeferencing of the available plans, including archive research

- supplementary surface and underground surveys of the adit, its damage patterns and light holes
- preparation of up-to-date mine plans, including sections and special representations

Mining-technical situation

- geometry, support and condition of the water-bearing adit, including adjacent mine workings
- ventilation conditions in the entire adit area, including the emission behaviour of mine gases
- spatial functionality and mode of operation of the water flow in the mine workings, e.g. through raises or winzes and also through backwater

Other

- subsequent uses of the mine workings and existing or planned surface use
- legal requirements

Determining the aforementioned subject areas or their content is necessary in order to be able to identify and assess the possible manifestations (forms of damage) and the associated risks, depending on the load case (see Section 8).

7 Monitoring

An adapted monitoring programme is necessary for assessing the functionality of drainage galleries. This can then reveal, where applicable, a change in the mine water level, the discharge and/or the mine water quality. How extensive such monitoring needs to be depends essentially on the discharge of the adit. In addition, the number and size of the damage scenarios that have occurred so far, such as crown holes, underground collapse zones and surge-like water discharges, are of importance. Furthermore, the respective use of the ground surface must be taken into account. On the basis of the use of the ground surface, the possible damage in the event of failure of the drainage, e.g. due to waterlogging, instability of slopes or surge-like water discharges from the portal area, is to be derived.

8 Damage analysis and risk assessment

8.1 Forms of damage to drainage galleries

In connection with drainage galleries, the manifestations (damage) caused by abandoned mines, especially as a result of extreme precipitation, can be divided into two zones of influence:

- damage-relevant events at the surface
- damage-relevant events underground

Surface

- ground subsidence and crown holes above the adit route where the overburden is thin

- waterlogged zones in the portal area as a result of a portal collapse or a defective Rösche
- sudden or surge-like discharge of water from the portal area after a collapse or partial collapse of the adit (“mine water burst”)
- surface water falling into washed-out, mined-through near-surface mine workings
- liquefaction of loose material (e.g. ochre) and its transport into the receiving watercourse

Underground

- partial or complete collapse of water-bearing sections of the adit and backwater
- formation of upward (chimney) collapses
- flooding of drifts and stopes as standing water zones as a result of flow obstacles
- vertical and horizontal relocation of material and jamming
- in the case of disturbed discharge, uncontrolled reversal of the flow direction of the adit water and discharge into lower or higher adits or drifts, which in many cases results in the reactivation of adits or drifts that had run dry.

According to the current state of knowledge, most damage occurs at the time of extreme precipitation or immediately afterwards. Late effects can still be detected decades later.

8.2 Classification of water-bearing adits taking risk assessment into account

The risk assessment with the assignment of risk classes is based on the 1st recommendation of Working Group 4.6 “Abandoned Mines” of 2004, “Geotechnisch-markscheiderische Untersuchung und Bewertung von Altbergbau” [Geotechnical and mine-surveying investigation and assessment of abandoned mines], and its supplements. Table 1 summarises the risk classification.

In numerous mining districts, there are several drainage galleries at different elevations. Depending on the size of the district and the hydrogeological situation, the quantities of water discharged vary, and with them the possible extensive, damaging water discharges, especially during extreme precipitation or snowmelt. In the main, it can be assumed that a hydraulic and geotechnical ranking (prioritisation) arises between the existing drainage galleries. Taking into account the existing mine workings in the respective hydraulically closed part of the district, and in particular their elevations, the adits acquire a differentiated significance within the three-dimensional mine workings. As part of a geotechnical and hydrogeological analysis of the old mine workings, a risk assessment and a prioritisation of the drainage galleries between and within the individual risk classes are required.

Table 1: Simplified scheme for assigning risk classes

Safety	Risk class	Characteristics	Need for action
"Unsafe"	I (red)	Very high risk (e.g. large active rock and rock mass movement, large accumulation of standing water in the discharge area, active landslides)	**Immediate need for action**, operational engineering and mining-technical measures – "imminent danger"
	II (yellow)	High risk (e.g. medium to minor active rock and rock mass movement, medium to minor accumulation of standing water in the discharge area)	**Prompt, planned need for action** for engineering and mining-technical measures
	III (green)	Medium risk (e.g. inactive rock and rock mass movement, unknown properties of the abandoned mine object)	• **Need for clarification or investigation** • Monitoring (observation and control)
Limit risk			
"Safe"	IV (blue)	Permanently secured object, residual risk remains, unimpeded water discharge, also subsequent use of the object	• **Monitoring** (observation and control) • if required **maintenance**
	not applicable	Closed or no influence on safety at ground level, residual risk remains	• **No measures** • Only in special cases inspection of the closure condition (e.g. shafts of potash and salt mining)

An updated mine plan with special representations is the prerequisite for classification. Sufficient clarification of the geotechnical and hydrogeological rock mass and stability conditions as well as of the mine water situation is the reliable basis for all further engineering, mining and drilling measures. Technical investigation and assessment should therefore take precedence in decision-making.

Owing to the hydraulic conditions, the long-term behaviour of the rock mass and the use of the ground surface, the following prioritisations of the drainage galleries of a district arise within the respective risk classes:

- The deep water-bearing adits of a mine drain by natural gradient via a Rösche to the receiving watercourse: the long-term stability of the adit perimeter is ensured by support that is stable in the long term. The unhindered discharge of adit water from the adit route, including its branches, and the drainage of the rock mass traversed must be taken into account. From a hydraulic point of view, the adit cross-section is to be kept as constant as possible over its entire length. Timber installations and support as well as nozzle-like constrictions of the cross-section are to be avoided. Depending on the size of the district, one or more drainage galleries may exist at this drainage level. Suitable light holes and shafts are to be selected for inspecting and maintaining the function of the adit.
- The next higher drainage level within the mine workings: in many cases, these drainage galleries can be assigned to an older mining period. Compared with the lower level, they generally discharge less water to the receiving watercourse. However, they are of great

importance for draining the middle and upper parts of the rock mass altered by mining. The key points in remediation are an intact and inspectable portal area up to about 50 to 100 m of the adit route, suitable light holes or shafts and sufficient long-term stability of the adit perimeter in the aforementioned section. It must always be checked whether vertical mine workings are present and can be used to let mine water fall to the lower drainage level. Depending on the in-situ rock mass, vertical or inclined boreholes are also suitable for vertical water conveyance.

- The oldest adits are usually located in the uppermost part of the mine workings. Owing to their proximity to the surface, they are subject to stronger, time-lagged, precipitation-dependent fluctuations in the water flow of the mine workings. Not infrequently, they are dry for long periods or carry only limited drainage water, which can lead to partial waterlogging in the portal area. Suitable infiltration points (e.g. soakaways, gravel packs) in the wider portal area, pipe connections for orderly water discharge or the construction of smaller dams for limited backwater as well as orderly letting-down of water via vertical mine workings or boreholes to a lower elevation are possible. The portal and the first metres of the adit (approx. 10 m) can be permanently closed by manually placing coarse, water-permeable stone packings.

This three-way division of drainage galleries often also reflects the stepwise vertical development, in particular of vein- and seam-type deposits.

Based on this three-way division, fundamental conclusions and graded remediation levels arise for the remediation of drainage galleries with regard to the permanent assurance of the functionality and inspectability of drainage galleries in order to guarantee public safety and to avoid flood damage.

In principle, these adits are assigned to the remediation category “permanent securing”. In this category, monitoring to be specified must always be taken into account.

9 Principles of remediation measures

Remediation measures on drainage galleries are to be assessed, planned and implemented using mining techniques in accordance with the principles of permanent functional preservation and inspection (monitoring), the undisturbed discharge of adit water, and the spatial drainage of rock mass water and mine water in the area of the entire adit section and the entire mine workings. The occurrence of possible mine gases and their transport with the outflowing mine water must be taken into account. The aspects of the perpetual burden of a water-bearing adit are also to be selected on an object-specific basis as part of long-term stable remediation measures for the surface and underground. Proven permanent securing and mining-technical closure methods are to be used.

- As a rule, remediation of active drainage galleries should start at the inlet of the Rösche into the receiving watercourse and proceed against the rise of the adit. The dimensions of the Rösche must always be adapted to the flow cross-section of the portal area. Temporary dewatering must always be planned for in a remediation. The problem of

standing water and the possible occurrence of surge water must be taken into account during the remediation work.

- From a hydraulic point of view, adit branches and junctions are to be classified as mine workings of equal rank to the main course of the adit. However, in a partial remediation of drainage galleries, only local zones of weakness can be eliminated.
- In general, timber support and installations are to be removed from the adit section. Timber support is to be replaced by permanent support. Timber deposits are to be effectively secured against being washed away.
- If a larger mine has water-bearing adits at different elevations, water can be let down from the level above to lower levels via vertical mine workings, boreholes and/or backwater, provided there is sufficient knowledge of the underground water pathways. Any remaining drainage water can be infiltrated in a suitable surface area. The prerequisite for the differentiated allocation of adits is a risk-oriented hydraulic classification of all water-bearing adits of a self-contained mine.
- Drainage galleries should be inspected at certain intervals (recommended every 1 to 5 years or promptly after extreme water events) and remediated if necessary. Accessibility on foot is preferable here. During remediation, nature conservation and, where applicable, other aspects must be taken into account in each individual case.

10 Subsequent use of drainage galleries

The question of subsequent use of active drainage galleries or parts thereof should always be asked before remediation. Above all, inspection of the object and maintenance of the facility would thus be ensured efficiently. The following key areas for subsequent use can be mentioned as examples:

- visitor mine with various experience areas depending on the size of the mine workings
- material witness of mining water management (visitor mine)
- water use (drinking and process water)
- geothermal use of the adit water
- therapeutic gallery
- fish farming facility
- seismological station
- underground flora and fauna biotope
- combinations of different types of use

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